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ORIGINAL ARTICLES.

SUCTION ANEMOMETERS.

By GEORGE E. CURTIS.

The wind produces a variety of mechanical and physical effects, and it is evident that such of these effects as are proportional in their degree or intensity to the wind velocity may afford, by their measurement, an indirect means of its determination. A current of air sets in motion a system susceptible of rotation about an axis, produces an increase or diminution of pressure on different portions of fixed or constrained bodies, cools surfaces of higher temperature by convection, accelerates evaporation, and develops musical sounds of different pitch or intensity in properly constructed apparatus susceptible of vibration.

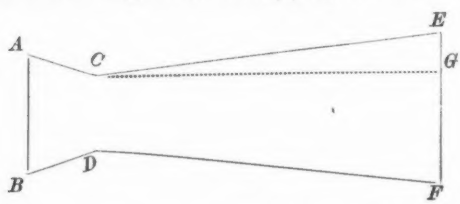
Anemometers, therefore, may be classified with respect to the physical effect of which they afford a measurement. The cooling, evaporative, and musical effects, do not bear a sufficiently definite and measurable relation to the wind velocity to form the basis of an accurate anemometer; but the first three effects, namely, rotation, increase of pressure, and diminution of pressure, or suction, have all been successfully applied to the construction of anemometers. To review the history of this last class—suction anemometers—and to present the theory of their action is the purpose of the present article.

Two quite different forms of such instruments have been proposed, corresponding to two distinct ways in which a moving fluid produces a diminution of pressure. In the first, the diminution of pressure, or the so-called suction, is produced by the wind blowing through a horizontal tube having a contracted section; in the second, the suction is produced in a vertical tube by the wind blowing across its mouth. Of these the second form alone, under the name of the Hagemann anemometer, has come into a limited use, as a part of the instrumental equipment of meteorological observatories.

The failure of meteorologists to utilize the phenomenon of suction more generally has been due partly to a general feeling of uncertainty as to its definite and measurable relation to the wind velocity. Such a feeling is expressed by Mr. J. K. Laughton in his "History of Anemometers" (Quart. Journ. Met. Soc. VIII, 1882, pp. 162-189). The theory of the flow of fluids, however, shows that in the horizontal contracted tube, the suction bears a relation to the velocity of the current no less definite than obtains between the velocity and the data given by pressure and rotation anemometers.

I. *The horizontal contracted tube.*

The first velocimeter based upon the measurement of the diminution of pressure produced by the current was proposed by Professor Overduyn, of Delt (Mechanics' Magazine, LXI, 1854), and consists in the application of Venturi's tube. This tube is composed of two truncated cones joined at their small ends and having the following proportions:



$AB = 18.$
$AC = 11.$
$CD = 15.5$
$EF = 23.$
$CG = 78.$

These proportions are such that the smaller end which is turned towards the direction from which the current flows corresponds very nearly with the shape of the *vena contracta*

formed at a simple orifice, while the larger portion $C\ D\ E\ F$ is such that the fluid entirely fills the tube as it flows toward $E\ F$. The theorem of Bernoulli furnishes the fundamental equation for the motion of the fluid through such a tube. This states that in steady motion, the energy of a stream due to its pressure plus the energy due to its velocity, plus the potential of the impressed forces must be constant. If p, v be the pressure and velocity at any point of a stream, ρ the density of the fluid, and V the potential of the external forces, the theorem will be expressed by the equation.

$$\text{Integral } \frac{dp}{\rho} + \frac{v^2}{2} + V = C \tag{1}$$

For incompressible fluids the equation becomes

$$\frac{p}{\rho} + \frac{v^2}{2} + V = C \tag{2}$$

which holds good without sensible error for the flow of gases where the charge of density during the flow is relatively small.

Taking account of the change of density, we have for the adiabatic flow of gases the equation

$$\frac{\gamma}{\gamma - 1} \frac{p}{\rho} + \frac{v^2}{2} + V = C \tag{3}$$

in which, for air, $\gamma = 1.408$.

In most cases involving the use of suction anemometers the change of density of the air is sufficiently small to render negligible the error introduced by the use of the formula for incompressible fluids.

The equations will, therefore, be developed for incompressible fluids, and to these equations a correction for adiabatic expansion may be applied in any case where it becomes appreciable.

For all portions of the stream lines in which the potential of the external forces remains constant, Bernoulli's theorem gives for any two points

$$\frac{p_1}{\rho} + \frac{v_1^2}{2} = \frac{p_2}{\rho} + \frac{v_2^2}{2}$$

Dividing by g, the force of gravity, and putting $g\,\rho = G$, we have

$$\frac{p_1}{G} + \frac{v_1^2}{2g} = \frac{p_2}{G} + \frac{v_2^2}{2g} \tag{4}$$

in which $\frac{p}{G}$ represents the head due to pressure and $\frac{v^2}{2g}$ the head due to velocity, and the equation states that in a perfect fluid under steady motion, throughout a space where there is no change in the potential of external forces, the total head of the stream remains constant.

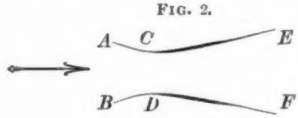
One additional relation must be added, called the equation of continuity. This expresses the evident condition that for any given bounded fixed space in a moving fluid, initially and finally filled with the fluid, the inflow must be equal to the outflow. For two cross sections of a bounded stream, w_1, w_2, we have the equation

$$w_1\, v_1 = w_2\, v_2. \tag{5}$$

That is, the velocities must be inversely as the sectional areas,

These two equations enable us to give a mathematical expression to all the phenomena of flow through conical and cylindrical tubes in which diminution of pressure, or so-called suction. is presented. These phenomena were first exhibited in the experiments of Bernoulli, and were afterwards made the subject of an elaborate series of experiments at Modina by Venturi in 1707 (Recherches expérimentales sur la communication latérale du mouvement dans les fluides, 1797). In experiments on the discharge of water from a circular orifice in a reservoir, Venturi found that the efflux was materially increased by the application to the orifice of cylindrical and conical adjutages, and that in such adjutages there is a diminution of pressure. The form of adjutage above described gave the maximum discharge, and has since been called by his name—Venturi's Tube.

FIG. 2.



If the sides of the tube be given a double curvature at the contraction, so as entirely to avoid a sharp edge, the perfect continuity of flow will be assured. In this form the following analysis of its action is obtained with the use of the preceding formulæ:

Let p_1, v_1, w_1 be the pressure, velocity, and section at *CD* p_2, v_2, w_2 the same quantities at *EF*; v_0 the original velocity of the current, p_a the atmospheric pressure; then, except for the small frictional resistance of the surface of the tube, we have

$$w_1 v_1 = w_2 v_2. \qquad (5)$$

$$\frac{v_0^2}{2g} + \frac{p_a}{G} = \frac{v_1^2}{2g} + \frac{p_1}{G} = \frac{v_2^2}{2g} + \frac{p_2}{G} \qquad (6)$$

If the discharge be into air, we have in all ordinary meteorological cases,* $p_2 = p_a$, whence

$$v_0 = v_2 \text{ and } p_a - p_1 = \frac{G}{2g}\left\{\frac{w_2^2}{w_1^2} - 1\right\} v_0^2. \qquad (7)$$

These results show:

1st. That at the contraction of the tube the original velocity of the stream has been increased in the ratio of the areas of the two sections *CD*, *EF*.

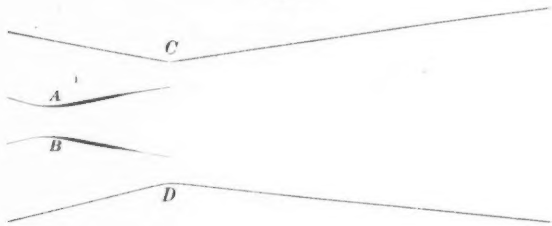
2d. That the diminution of pressure at *CD* is proportional to the square of the original velocity of the stream.

In the stream to be measured, Prof. Overduyn placed a Venturi's tube with the axis parallel to the direction of flow, and with the base of the smaller cone facing the current. A small tube inserted at the contraction conducted to a case, otherwise hermetically sealed, containing an aneroid barometer; this barometer accordingly measured the pressure at the contracted section. The velocity of the current is therefore completely determined from the observation of the pressure given by the barometer connected by a closed tube with the contracted section *CD*, together with the atmospheric pressure; or by one observation, if the diminution of pressure be measured in a u-tube manometer.

* In the flow of a gas from a simple orifice when the pressure within the reservoir is more than twice the atmospheric pressure, this equality no longer subsists. (Fliegner: Civil ingenieur, XX, 1874.)

The diminution of pressure produced by a given velocity of current may be largely increased by placing two or more tubes of different sizes one inside of another in such position that the discharging end of the inner tube lies at the plane of contraction of the larger tube, as in the following diagram.

FIG. 3.



Let $\frac{w_2}{w_1}$ be the ratio of the discharging section to the contracted section of Venturi's tube. By equation (7) the pressure at *CD* is

$$p_1 = p_a - \frac{G}{2g}\left\{\frac{w_2^2}{w_1^2} - 1\right\} v_0^2.$$

If p_2 v_2 be the pressure and velocity at *AB* (Fig. 3), then

$$\frac{p_a - p_2}{G} = \frac{v_2^2 - v_0^2}{2g} = \frac{\left\{\frac{w_2^2}{w_1}\right\} v_1^2 - v_0^2}{2g} = \frac{v_0^2}{2g}\left\{\frac{w_2^4}{w_1^4} - 1\right\} \qquad (8)$$

Similarly, the diminution of pressure at the contracted section of a third tube, placed inside of the second, would be expressed by the equation

$$p_a - p_3 = \frac{G}{2g}\left\{\frac{w_2^6}{w_1^6} - 1\right\} v_0^2. \qquad (9)$$

The device of multiplying the Venturi's tube has recently been tested by M. Eug. Bourdon (Comptes Rendus, XCIV, 1882, p. 229). In experiments made with single, double and triple tubes, in an air current produced by a fan or bellows, he found that in a current whose velocity raised the water one unit distance in a Pitot tube, the water in a u-tube manometer connected with the

contracted section of the single tube rose to 6; joined to the double tube, the water rose to 20, and with the triple tube to 80 or 90. These results do not exhibit an entire agreement with the above formulæ, bnt the evidence of accuracy and freedom from error in the experiments is not sufficient to give very much weight to the disagreement. The experiments indicate, however, that the additional tubes act as an obstruction in the stream and occasion a loss of velocity, so that the total effect as given by the preceding formulæ cannot be realized. A constant to be determined by experiment should, therefore, be inserted in the equations.

ARSON'S ANEMOMETER.

Another form of suction anemometer, similar in action to Venturi's tube, but of different shape, was proposed by M. Arson in 1875 (Assoc. Franc., 1875; Mem. Soc. Ing. Civ., Paris, 1876, p. 505). It consists of a cylindrical tube, narrowed by an interior contraction, as shown in Fig. 4. The suction is measured from

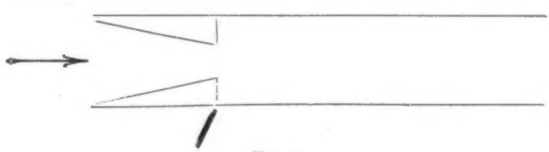


FIG. 4.

a point at or just beyond the contraction.

M. Arson assumes that when the diminution of the area of the tube by the contraction is small, as adapted by him, it will not produce any discontinuity of flow at the abrupt change of section. With this assumption the equation is the same as for Venturi's tube.

$$p_a - p_1 = \frac{G}{2g}(v_1^2 - v_0^2)$$

Arson then makes the ratio of the area of the contracted section to the area of the tube $1 : \sqrt{2}$ and so obtains

$$p_a - p_1 = \frac{G}{2g} v_0^2$$

In this case, therefore, the diminution of pressure at the contracted section is the same as the height due to the velocity.

Expressed numerically and taking account of variations in the density of the air under different temperatures and pressures, the formula becomes

$$v = 46.9 \sqrt{h \frac{P}{29.92} \frac{519}{459 + t}}$$

in which

v = velocity in feet per second,
h = height of water raised by suction in a u-tube manometer,
P = atmospheric pressure in inches of mercury,
t = air temperature in degrees Fahrenheit.

As already stated this formua is based on the assumption of no discontinuity, but, in general, for flow in a tube containing a sharp change of section, as in Arson's tube, there is an abrupt change of velocity and consequent discontinuity and loss of head due to shock. This loss of head must, therefore, be introduced into the equation for the action of the instrument.

Let v_0, p_a be the pressure and velocity of the current; v_1, p_1, w_1 the velocity, pressure, and area at the contracted section; v_2, p_2, w_2 the same quantities at the discharging end of the tube; $\frac{(v_1 - v_2)^2}{2g}$ equals the head lost in the shock.

Then $\frac{v_0^2}{2g} + \frac{pa}{G} = \frac{v_1^2}{2g} + \frac{p_1}{G} = \frac{v_2^2}{2g} + \frac{pa}{G} + \frac{(v_1 - v_2)^2}{2g}$

Let $c = \frac{w_1}{w_2}$; $v_0^2 = c^2 v_1^2 + (v_1 - c\, v_1)^2 = [c^2 + (1 - c)^2]\, v_1^2$.

In Arson's anemometer, $c = \frac{1}{\sqrt{2}}$ whence $v_0 = 0.765\ v_1$.

Without considering the dissipation of head in shock, the formula as given by Arson is $v_0 = 0.707\ v_1$. His calculated velocities, therefore, will need to be increased by the factor 1.082, by this consideration.

A much better instrument is obtained by making the enlargement a gradual one, as in Venturi's tube, by which perfect continuity of flow is secured and the introduction of the preceding factor avoided.

To test the working of his anemometer, M. Arson made a

series of very careful experiments. A tube containing his form of contraction was fitted to the cap of a gasometer. The actual velocities of efflux, which ranged from 10 to 20 meters per second ($22\frac{1}{2}$ to 45 miles per hour), were obtained by measuring the height through which the gasometer rose in a unit of time. The experiments showed that the real velocities were 94 per cent. of those calculated by his anemometer formula.*

The preceding theory of the suction anemometers of Overduyn and Arson gives a very simple relation between the wind velocity and the pressure indications that constitute the data of observation, and one that seems entirely free from neglected sources of error. The use of such an instrument presupposes, however, that the axis of the tube is always parallel to the direction of the current. When exposed for observation, it must, therefore, be attached to a wind vane in order to fulfil this condition; but the continual shifting of the wind and the oscillations of the wind vane renders the parallelism difficult to secure, and forms the principal source of error in the use of this instrument as an anemometer. If the wind vane to which the anemometer is attached have considerable stability, so as to reduce the oscillations produced by gusts, the difficulty may be largely overcome. Actual comparative observations are necessary to determine the accuracy that may be attained. A tube

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* M. Arson was unable to explain this difference. If the experiments be sufficiently accurate to assure that the observed discrepancy is a real one, the following considerations will serve to indicate its possible source. The diminution of pressure behind the contraction, where it is measured by Arson, is *not the same as at the contraction*. In the accompanying diagram of a tube with a sharp change of section, the line *AB* represents the bounding stream line of the continuous current, and the corner *ABC* is a region of discontinuity. As more fully explained in the following pages, the pressure within such a region of discontinuity is greater than the pressure in the current where the curvature of the bounding stream line is convex toward it, and less than the normal pressure when the curvature is concave. As shown in the figure, *AB* is concave to *ACB*; wherefore

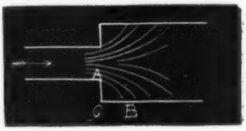

FIG. 5.

the pressure at *C* will be less than that in the adjacent stream, and the calculated velocities, therefore, will tend to be too large. This effect is opposite to that produced by the loss of velocity due to shock, and it seems probable that in the normal use of the instrument in a natural current, instead of in a current produced by pressure, the two effects would very nearly counterbalance each other, so that Arson's tables would give a close approximation to the true velocity.

inserted in the side of the anemometer tube at the contracted section conveys the pressure to the observing room, where it may be measured by a water or ether manometer, or by a delicate aneroid barometer enclosed in an otherwise tight case. In order that the reading of the instrument shall remain constant during an observation, a stop-cock may be fixed in the tube, by means of which the effect of the wind velocity at any moment may be caught and retained until the observation is satisfactorily recorded. It should be remembered, however, that the theory of the instrument properly holds good only for *steady motion*, and, therefore, is not strictly applicable for measuring velocity while gusts, or rapid changes in velocity, are taking place. At such times observations should be made, when possible, after a change in velocity has been accomplished and steady motion at a new velocity resumed.

An additional source of difficulty in the practical use of these forms of anemometers is the stoppage of the tubes by snow and sleet during the winter months—at the very season when its use would be especially valuable as a substitute for cup anemometers, which then for the same reason fail to preserve the accuracy of their indications.

It is highly desirable that practical endeavors be made to obviate the difficulties incident to the use of this form of suction anemometer, and the accuracy of its theoretical action secured to meteorology.

II. *The vertical suction tube.*

The Hagemann form of suction anemometer consists of apparatus for measuring the suction produced in a simple upright straight tube by the wind blowing across its top. This instrument, described by Hagemann* in 1876, has since been used at the central station (Copenhagen) of the Danish Meteorological Institute; but with this exception, it has not been adopted by any meteorological service for the registration of its published wind velocities.

The International Polar Commission recommended its use as a reserve instrument in the case of any failure in the action of

* Annuaire météorologique pour l'année, 1876, l'Institut météorologique Danois.

the Robinson anemometer; and in compliance with this recommendation, observations with the Hagemann anemometer were made by the Finnish station at Sodankylä, and by the Russian station at the Lena delta, where they were used to complete the published wind velocities whenever the cup anemometer was in need of adjustment or repair. This is about the extent to which the Hagemann anemometer has been used in organized work.

Although known as the *Hagemann* anemometer, the same principle was proposed and put to a practical test by Mr. A. E. Fletcher* in 1867. Mr. Fletcher assumed that the suction in such a tube is equal to the height due to the velocity [i. e., the height through which a body must fall in vacuo to attain this velocity], and states that the results of his experiments agreed very closely with this hypothesis.

Hagemann's experiments, with artificial currents, showed a suction less than would result from the velocity according to this law; but as the difference seemed to diminish when the excess of pressure in his blast was reduced, he concluded that when there is no excess of pressure in the blast, that is, in the case of a natural current, a suction equal to the pressure due to the velocity would be realized.

Both Fletcher and Hagemann suggested also for a portable anemometer the use of a bent tube, as in figure 6. Across the top of one end, *a*, the current of air to be measured blows normally to the axis of the tube; the other end, *b*, is turned to face the current. In this form, which is essentially a combination of the Hagemann and Lind anemometers, the effect of a current was assumed by both Hagemann and Fletcher to be twice that in a single Pitot tube.

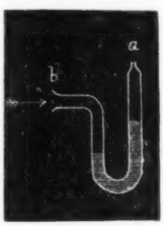

Fig. 6.

The theory of fluid motion fails, however, to confirm this relation in any general way. The problem is as follows: Given a fixed vertical straight tube immersed in a fluid current flowing horizontally across its open top; to determine the diminution of pressure

* Brit. Assoc. Rep., 1867, ii, 33; 1869, ii, 48.

produced therein by the current, in terms of its velocity and density.

This problem is much more difficult than that of Venturi's tube, and no general solution, so far as I know, has yet been given. To obtain an idea of the nature of the forces producing the diminution of pressure in the tube, and the form of their expression, the problem is best approached by an analysis of the action of the stream lines about the orifice of the tube.

Figure 7 represents the orifice of a tube over which a current of fluid passes, and the general character of the deviation of the stream lines. The end of the tube presents a sharp edge to the flow of the stream, and a small region of discontinuity is formed above the orifice.

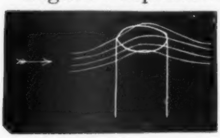

Fig. 7.

The stream lines will be slightly crowded together owing to the obstruction of the tube, and their velocity will be slightly increased to the extent required by the diminished section of the current. The pressure along the line of increased velocity will, therefore, be diminished in the ratio of the square of the velocity. For a large obstruction like the side of a house, this effect would no doubt be sensible inasmuch as the wind velocity is well known to be materially increased; but for small obstructions, like a tube, it could scarcely become appreciable.

The principle portion of the decrease of pressure in the tube arises from the fact that the pressure in the region of discontinuity at the orifice of the tube is not the same as the pressure in the contiguous stream, but is determined by the curvature of the bounding stream-lines. This is a general principle, applicable to any case of discontinuity, and deserves careful attention, especially as it is frequently neglected in the analysis of discontinuous motion. For example, for a lamina immersed transversely in a stream, neglecting friction, Lord Rayleigh* says, "behind the lamina the fluid is at rest under a pressure equal to that which prevails at a distance."

But from ordinary observation we know that behind an ob-

*On the resistance of fluids—Phil. Mag. ii, 1876, 434.

stacle, such as a pier in a river, the fluid is not at rest, but is in continuous motion, and that the hydrostatic pressure upon the rear face of the obstacle is materially less than the pressure in the unobstructed current.

It is proposed to show that these actually observed conditions are initially induced by the curvature of the stream lines. The general principle obtained in the case of a plane lamina may then be applied to the case of the pressure in a tube placed at any angle to the direction of the current.

Let AB be the section of a plane lamina immersed transversely in a stream of infinite extent, and let the curved lines represent the stream lines bounding the region of discontinuity. On the anterior side of the lamina, the stream lines are convex to AB; at the back of the lamina, the stream lines from A and B to C are concave, and from C to O are convex to AB. From S to A and B the stream lines exercise centrifugal reactions towards the plate and develop the dynamic pressure that is experienced on its front face. From A and B to C, the lines exercise centrifugal reactions outwards; now as the pressure in the continuous stream is determined by the condition of steady motion that $p + \frac{\rho v^2}{2} = c$, these centrifugal reactions do not increase the pressure of the stream, but *tend to decrease the pressure behind the plate* to an extent equal to the force of the reactions.

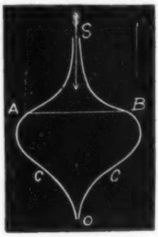

FIG. 8.

At C the curvature changes, so that from C to O it tends in like manner to increase the pressure over the adjacent portion of the region of discontinuity. Taking the region as a whole, therefore, the resultant action of the external forces is to produce differences of pressure—a disturbance of its equilibrium. The tendency to a restoration of equilibrium, thus disturbed, sets up motion from the region of pressure-excess to that of pressure deficiency, and the equilibrium between the region of discontinuity and the contiguous stream lines is thereby de-

stroyed. An increment to the mass of water close to the back of the plate produces a pressure increment that is not counterbalanced by the pressure in the stream; and the excess of fluid is forced into the stream, where it is rapidly carried down stream by the moving current; thus the original diminution of pressure tends to be maintained. This is accomplished by the production at the bounding surface of irregular motions, whirls, and eddies, which often extend inward throughout the whole region of discontinuity. Such a condition is commonly termed a condition of fluid friction, to which the resulting diminution of pressure is due, and all this is ordinarily neglected in the theory of fluid motion. But it has been the purpose of this analysis to show that this so-called fluid friction is excited by the differences of pressure within the region of discontinuity itself, and that these differences of pressure are initially developed by the curvature of the bounding stream lines. For the particular case, therefore, in which the stream lines are straight, the pressure will not be changed by the moving current. This case finds its well known application in measuring the pressure of a current by means of a manometer tube fixed laterally in its bounding surface. For a cylinder immersed in a stream with its axis parallel to the current, the action is much the same as for a lamina, except that in this case the stream lines pass the rear face parallel to the normal direction of the current instead of with an outward inclination.

For the purposes of anemometry the relation between this diminution of pressure and the velocity of the current must be accurately known, and the preceding analysis leads us to the form of the function, and shows the limits of its quantitative value.

The centrifugal reactions of the concave stream lines, shown from *A* and *B* to *C*, fig. 8, originate a diminution of pressure proportional to $\frac{mv^2}{r}$ on each unit of the bounding surface, where m is the mass of fluid deflected per unit of area, and r the radius of curvature. If we may assume that for the same tube, placed

with its axis parallel to the current and with its open end down stream, and for the same density of fluid, the shape of the stream lines as practically constant for all velocities neither very small nor very great, the radius of curvature r, at any point, will be independent of the velocity, and the expression becomes proportional to v^2. The total diminution of pressure originated by these radial, outward forces can be realized only when the fluid friction is sufficient to maintain it steadily. For a lamina immersed transversely, the mass of fluid to be carried away is proportional to its area, while the surface of friction is proportional to the perimeter; consequently, the effective diminution of pressure on its rear face must, in general, vary inversely with the size of the lamina. Thus, if for a lamina or tube of radius r the maximum diminution of pressure is just approximately attained, for a lamina of radius $r + dr$, the ratio of the area to the perimeter will be greater, whence the work to be done per unit of time will be greater than the means of doing it, and the average diminution of pressure must be less.

With small tubes in which the maximum effect is nearly attained, the variations in pressure for small changes in size are insensible. Consequently, for tubes decreasing from radius $8^{mm.}$ down to capillary diameters, Hegemann found no difference in the suction.

If the transverse lamina, or the tube parallel to the stream, be turned to an angle with the current, the mass of "dead fluid" diminishes faster than its perimeter, and, consequently, for all tubes in which the maximum diminution of pressure is not approximately attained, an increase in the effect ought to take place. This result, indicated by theory, is confirmed by experiment.

In a paper read before the British Association in 1882,* Lord Rayleigh says that the maximum updraught of a chimney occurs with an upward wind making an angle of 30° with the vertical.

In experiments made by Ewbank and Mott (Journal Franklin

* See Symons's Met. Mag., London, XVII, 1882, 130.

Institute, Phila., IV, 1842, 104), it was found that with the axis of a tube parallel to the direction of a current, the suction at the mouth turned down stream was from 1½ to 2¼ inches of water; turned to *45° with the current, the suction was* 3¼ *inches, and at 90° was* 2½ *inches.**

Similar experiments made by a committee of the American Academy of Arts and Sciences (Report by Dr. M. Wyman, Proc. Amer. Acad., Boston, I, 1846–48, 307–324) gave the following velocities induced in a tube by suction. Tube parallel to current, opening turned from the blast, velocity 0.76 ft. per second. Tube making with the direction of the blast angles of

30°	45°	60°	90°	
1.15	1.29	1.23	0.83	feet per second.

For angles of the tube greater than 60° only one side of the region of discontinuity in the fluid is a surface of friction, since the other side rests upon the mouth of the tube; the diminution of pressure is therefore less than at angles from 30° to 60°.

These various results may be expressed in the following propositions, which may be considered to contain the basis of the theory of the straight tube suction anemometer:

1st. The diminution of pressure in a tube with one end immersed in a fluid current is proportional to the square of the velocity of the current, but varies in amount with the density of the fluid, with the size of the tube, and with its angle with the direction of the current. 2d. In general, for any given case, the quantitative coefficient must be determined by experiment. 3d. In the most advantageous positions, and for small tubes, a diminution of pressure approximately equal to the pressure due to the velocity may be attained—at least this is a limit towards which the suction effect in a straight tube approaches.

As compared with the suction anemometer of Overduyn, the straight vertical tube of Fletcher and Hagemann has the disadvantage of an undetermined and perhaps an uncertain coefficient. But on the other hand it possesses a decided advantage

* The strict comparability of these results is somewhat doubtful, since the mouth of the tube in the different positions was, apparently, brought by rotation to different distances from the orifice of the blast, and hence became subject to different velocities.

in that it does not have to be connected with the wind vane, and suffers no loss of accuracy with change of the wind direction.

For the registration of the suction in the tube, Hagemann's apparatus, as constructed and sold in Copenhagen, employs the tension of a simple coiled spring, which as a measure of pressure is apparently inferior in accuracy to a delicate aneroid barometer or a spirit manometer.

The present paper has dealt almost exclusively with the history and theory of suction anemometers. The writer would be glad to receive material for the preparation of a supplementary paper discussing the practical working of these instruments, and the limits of their accuracy.

INDIAN CYCLONE OF OCTOBER, 1864.

By Mrs. Jane Napier Brodhead.

These are my recollections of a cyclone in India. It was on the 5th of October, 1864, that I went through one of the most terrible cyclones on record. Even in regions where visitations of this kind are frequent, this one was considered the worst that had been experienced in a hundred years.

Cyclone is a Greek word, signifying "Circle," to which is added an augmentative suffix; it certainly is a very unpleasant "circle" whose diameter varies from three to five hundred miles, and whose center travels anywhere from twelve to thirty miles an hour. It is *rotatory*, that is, it spins along like a wheel, and *giratory*, like a disc revolving rapidly on a pivot. To use a familiar illustration, it is like those eddies of dust one sees on sandy roads in a summer storm.

This eventful 5th of October began wet and windy; nothing very extraordinary at this time of the year, for though the rainy season, that period of small deluges, was over, it was the month of the monsoons, periodical winds which blow continuously in the same direction at certain times, like the tradewinds. There seemed no likelihood of its clearing up, and we settled down to draw and paint, little thinking what a day would bring forth.

Towards noon the wind began to blow in a most alarming manner, and we left our work to watch the weather. At 2 P. M. it became evident that we were going through no ordinary experience; indeed, we began to be seriously alarmed. Our house had three stories, which means a very high one in Calcutta, where the ceilings are so elevated; it was in a rather exposed position, too, being situated on the Chowringee road, separated from the Strand, or riverside, by the "Maidan," a large common laid out with banks and elegant drives. If we were more exposed to the blast as a corner house, we were at least, not in danger of being crushed by the fall of neighboring edifices; so we resolved to take our chances, after using every precaution in the way of securing the windows and doors with cords and chains. Indeed, there was nothing better to be done. How could we be sure that any other building would offer us a safer shelter? And we could not stir out without running into great and certain dangers.

A cyclone is more terrible than fire or water, I think, for if your house is menaced by these, you can at least rush into the street; but in a cyclone you are "weather bound" in a most cruel sense. There is something so uncanny, too, in this wrestling with an unseen, incorporeal enemy, who with uplifted voice and a strong arm tries to break into your house by every aperture. If we had allowed him to lift but one venetian, he would probably have lifted the roof; as it was, we weathered the storm, losing only such accessories as verandahs, wooden awnings of windows and ornamental balustrades.

From the top floor I surveyed the river and the neighborhood as far as the eye could reach on either side of the "Maidan." It was a sight never to be forgotten. The Cathedral, from its situation on an eminence, and its form, a bastard gothic structure, was the first to suffer. The heavy sheet iron roofing, weighing many tons, was seen flying around in fragments like a flock of condors on the wing. Zinc sheds, wooden awnings, verandahs of every description, soon shared the same fate; massive beams, doors and windows were whirled around like straws. Many edifices less solidly built than ours crumbled like chil-

dren's card houses; others were completely dismantled, all the outer walls being blown down. Calcutta, the capital of the British Empire in India, is a very important port, though it is not on the sea, but several miles from it on the Hoogly, a branch of that giant river the Ganges. The stream is so wide and deep that it forms a fine harbor, which, at all seasons of the year, is covered for miles with vessels from all parts of the world, which only remain long enough to load and unload, then sail off and make room for new comers. The Hoogly is a very treacherous river; not only is there an undercurrent which makes swimming almost impossible, but it is subject to a tidal "bore" which comes rushing up from the sea like a great wall in the middle of the stream. Any small craft found within its range is of course swamped; the only safety is in keeping out of its way, near the shore. Imagine this immense volume of yellow water, a mile broad and fifty feet deep, tearing along at the speed of a race horse! But this was only a small episode, hardly noticed in the great tragedy which was being enacted.

As the cyclone advanced in its rotatory movement, the compact mass of vessels began to drift from their moorings and the forest of masts bent and swayed under the violent action of the wind, much as the giants of the forest do in the same case. As I watched them, it seemed as though I could hear the cracking spars and the shivering beams, snapping like the limbs of a tree, as the wind roared through the tattered sails and shreds of cordage, whirled about like spiders' webs in the blast. As for the small craft, the dinghies and the Indian barges of every description, they went down without a moment's resistance, and their native crews were drowned by hundreds like so many water rats. There is little or no twilight in Calcutta, and the gathering gloom put an end to my observations, but it was easy to conjecture how it would all end. Even if the cyclone could have been foreseen, and electric signals been made from Kedgeree point, out at sea, it would not have been possible to avoid the disasters on the water. Fewer lives might have been lost if the crews had abandoned their crafts and come ashore in time, but no moorings or sheet anchors were of any avail when chains

were snapped like tow. Since a hundred years there had not been such a cyclone, and we are rarely prepared to meet emergencies which only occur once in a century.

Towards 10 P. M. the violence of the wind began to abate; we hoped that the worst was over, and thought of retiring to rest after the excitement of the day. The house appeared to have withstood the violence of the cyclone, but there was no telling how badly the walls might have been shaken, so we improvised beds on the ground floor, in order to have a chance of escape if they did collapse.

The next morning rose calm and radiant as a spring day. All nature smiled serenely as though she knew nothing of yesterday's unprecedented calamity, and had never heard of the 90,000 victims which the black-winged tempest had made in one fell swoop. After breakfast we drove along the banks of the river for several miles on either side of Calcutta, to see the dire effects of the cyclone. It was indeed a sight never to be forgotten. The day before the river was covered for miles by vessels of all kinds, from the 500-ton bark to the 5,000-ton passenger steamers. Not one of them was left afloat. It was ascertained that 210 had completely disappeared under the waters, the others were stranded, being carried inland, more or less, according to their size and the manner in which they were struck. A P. & O. steamer (Peninsular & Oriental line) of 1,600 tons was carried so far away into the paddy fields (rice in the ear is so called) that to float her back they had to dig a canal, at a cost of $60,000.

Along the left bank of the river is a row of solid one-story buildings, belonging to the custom-house. Of course these were submerged by the angry waters, which had also crumbled away, in many places, the embankments of the Strand, ten feet above high-water level, and solidified, with brick and concrete, the labor of many years. A large vessel (I forget the tonnage) was carried inland by a great impact, and left high and dry on these buildings by the receding waters.

The black mass impressed itself on my young imagination, and I remember how impatiently I watched the complicated

preparations for launching the unhappy vessel, which seemed to suffer from the false position in which it was placed and the gaze of the curious multitude. Many vessels were fortunate enough to be cast on soft, low ground, where they remained snugly embedded, and it was comical to see people quietly breakfasting on deck, as if it were quite natural for ships to be lying on their beam ends about a hundred yards or so inland. The steamers which happened to be up the river, outside the vortex of the cyclone, were in great demand for towing off the stranded vessels, and large fortunes were made by the lucky owners. It is always so in great calamities; a few enrich themselves while thousands are impoverished. Many wrecks in shallow parts of the river had to be exploded, as they would have been dangerous for the navigation.

About sixteen miles from Calcutta are the "Botanical Gardens," a park laid out by Lord Wollesley, seventy years previously. Picnics—a very popular institution in Calcutta—were always given there, the guests sailing or driving down. The place now looked like a great battle-field, where the genii of the air had waged war against the giants of the forest and laid them low. Gigantic trees, of more than secular growth, were torn up by the roots like weeds, as if the enemy, angered by their brave resistance, had not been satisfied with snapping them in twain. What is still more remarkable, even bamboos, the most slender and flexible of trees, offering so little surface that a cannon-ball cannot injure them, were torn up from the ground, with their long, tenacious roots which almost identify themselves with the soil. Every hut or dwelling in the Indian quarters was of course blown down, while near the mouth of the river whole villages of natives and Europeans were completely submerged; all escape was physically impossible.

It is estimated that about 90,000 lives were lost in this terrible cyclone. The financial losses could hardly be put into figures.

MOUNT WASHINGTON AS A METEOROLOGICAL STATION.

By H. A. Hazen.

There has been recently quite an agitation regarding the value of Mt. Washington as a meteorological station. It seems to me that without question it is the most important station in the whole world, and certainly no individual station has ever had its observations discussed as thoroughly or by so many investigators. It may be well to state some of the advantages of this station and also to call attention to some of the results derived from a study of its records. The advantages may be briefly enumerated as follows:

1st. It is admitted by all meteorologists that the "power" of the storm is situated at some height in the atmosphere and many consider this height, in most storms, about at the summit of this station, 6,300 feet above sea level. The incalculable advantage of observations at this point will be recognized. Thousands of dollars may be spent in getting two or three observations, at this height for a few winters, by means of a balloon, but here the conditions are almost reversed—thousands of observations for a few dollars.

2d. This station lies exactly in the track of storms that have frequently traversed the whole length of this country, and we are enabled to determine almost precisely all the conditions of the storm at its seat of power. The mountain stations in Europe lie far to the southeast of the general track of storms; even Ben Nevis in Scotland, which is about 4,400 feet in height, is generally southeast of the storm centre.

3d. This mountain rises almost solitary and alone from the plain beneath. Only 12 miles to the eastward we find Gorham about 700 feet in height.

4th. The latitude (44° 16′) makes the station a most desirable one for a study of atmospheric conditions above the earth in the temperate regions.

Let us now turn to the practical results which have been obtained. Professor Loomis was the first to fully realize the

importance of this station. In his first "Contributions to Meteorology" prepared in the early part of 1874, he determined the ratio of the wind's velocity at Mt. Washington to that at sea level as 1 to 5.5 and the velocity of the resolved portion of the wind's motion in the western quadrant, which acts in the same direction as that of the average progress of storms was 43 miles, while the mean velocity of the storm was only 25.6 miles per hour.

In Professor Loomis' second paper there is a continuation of this discussion including the action of the wind during the progress of a high as well as a low area with the important results, that at 6,000 feet in both high and low areas, the general current has a motion toward the east. Professor Loomis was the first to show that the fluctuations of pressure at Mt. Washington lag some hours behind the fluctuations at the earth's surface, a subject which has aroused the deepest interest. Among many other determinations from these observations I mention the following:

"Sometimes low areas result from a circulation of the surface winds which does not extend to the height of 6,000 feet;" "the greater the depression of the barometer, the greater is the height to which the system of circulating winds extends." During the progress of a low area, the change of wind to the east is 11 hours earlier at the base than at the summit of Mt. Washington, and the change back usually begins at the base 5 hours earlier. I have given only a few of the condensed results of Professor Loomis' work.

One of the most important discussions of these observations has related to their use in determining a proper reduction of barometric readings to sea level. Lieut. Dunwoody presented an exhaustive discussion of hourly readings on Mt. Washington in 1876, and from time to time the observations have been used for obtaining a practical reduction to sea level and have also served to check theoretical discussion of the same question as well as that of hypsometry.

The conditions of temperature and air pressure at some height above the sea are very intimately connected with the

theory of storms, and these are manifestly best determined by observations in the atmosphere and not by vague paper theories.

The cause of the general trend of storms from west to east has given rise to a lively discussion, and possibly no question in meterology has been so generally considered. The movements of clouds have been most carefully studied, but unfortunately these fail us at exactly the most critical periods, namely, during the progress of storms, when the lower clouds hide the upper. In the Journal of the Franklin Institute for July, 1888, the present writer has shown:

1st. The wind on Mt. Washington has nearly the direction of the highest clouds.

2d. The wind velocity near the time of the passage of the storm was 53 miles per hour, while the storm moved 34.

3d. The velocity of the wind during the passage of a high area was about 22 miles per hour.

Since the storm tracks were nearly due N. E., while the mean wind direction was toward a point a little south of east, it would seem that the "power" of the storm must be below the summit of Mt. Washington. A careful study of each storm as it passes near Mt. Washington must give us great aid in solving the problem of its movement, whether it is in the general drift of the atmosphere or whether other causes affect its motion.

The question of the formation of rain, it would seem, might be well studied in connection with observations at this station. It has been suggested that the increased fall of rain, on a mountain, may be due to warm vápor-laden winds passing up the side which condense their moisture on reaching the lower temperature at the top. Careful inquiry has shown that the fall of rain on Mt. Washington has precisely the same appearance as at the earth's surface, and it does not seem to come up the side of the mountain. The rain and wind roses at the base and summit of this station are quite interesting. I selected out all the cases of rain or snow where .50 in. or more fell at Mt. Washington in 16 hours and distributed them by the wind direction at the time. The same was done with the simultaneous obser-

vations at Burlington and Portland. The table contains the percentage of the total fall of rain with each wind.

RAIN AND WIND AT MT. WASHINGTON AND BASE.

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.
Mt. Wash....	3	5	3	10	9	12	13	44	1
Burlington..	36	3	3	6	32	3	4	7	6
Portland.....	19	20	9	13	12	8	4	7	8

We find nearly half the rain at the summit falls with a northwest wind; at Burlington there seems to be a considerable local influence possible from Lake Champlain; while at Portland north and northeast winds give the most rain. There may be here an inkling to a solution of the question whether there is an uprush of air in a low area by which the rain is produced.

September 8, 1888.

CORRESPONDENCE.

A LUNAR RAINBOW.

To the Editors:—After many years waiting I have seen a genuine and perfect *lunar rainbow.* It occurred this evening at 8 o'clock and lasted five minutes, remaining bright and perfect until about one-half minute before vanishing. When first seen only the south end of the arc was visible, but very soon it became complete and remained so.

The day has been cloudy, and the evening is sultry, threatening rain; wind S.W. and high. The sky was overcast, except a small portion in the S. and in the S.E., near the moon, where some stars were visible between scudding clouds. The moon was about an hour high, bright and full, or nearly so. In the N.W., back of the bow, the top of which seemed to be about 45° above the horizon, were heavy nimbus clouds, but no rain fell in Dover. The bow stood out very distinctly against the dark back-ground, and was the color of pale moonlight. With the

sharpest scrutiny I could not detect any prismatic colors, nor could Captain W. H. Morris, who also witnessed the phenomenon. The bow was narrow.

Yours sincerely,

ERWIN F. SMITH.

DOVER, DELAWARE, August 21, 1888.

LOCAL INFLUENCE IN TORNADOES.

To the Editors:—This place is situated like Cawker City, mentioned in the July number. A small stream skirted with heavy timber divides to the S.W. and flows around the town.

Twice, yellow, olive-green, low-lying clouds in N.W. and W., divided and passed away without damage, except tremendous hail.

Once a heavy blue-black cloud in the N.W., with a steamy, puffy, hay-mound cloud in the S.W., piling itself up in banks of steamy clouds, with small light clouds passing swiftly from the black cloud to the steamy one, all passed away without damage The steamy cloud sent an off-shoot, moving rapidly east, blowing down fences and trees.

But at Irving, Kansas, the location is similar, and they had two tornadoes in one day. J. F. LLEWELLYN.

MEXICO, MO., August, 1888.

CURRENT NOTES.

TEXAS WEATHER SERVICE.—An addition to the sisterhood of state services is that of Texas, of which the first two numbers of the *Monthly Weather Review* are for June and July of this year. S. O. Young, M. D., is director, and Allen Buell, Signal Corps, assistant director, with headquarters at Galveston. Twenty-six stations report in July. Texas offers a very wide and profitable field for such a service, and, judging from these reviews, it has been undertaken with the usual Texan energy and push.

THE MONTHLY BULLETIN of the Central Meteorological and Magnetical Observatory of Mexico has resumed publication

after a lapse of a year or two. The new series is in quarto form, much more convenient than the previous folio. We have the first five numbers, beginning with January of this year. They contain twelve pages each, which are devoted to a résumé of the hourly observations at the observatory, with daily account of the weather in the Valley of Mexico. In addition to this are given reports from 26 other stations scattered over the republic. These are accompanied by occasional papers of a general character, and other matters, making altogether a valuable monthly.

A Signal Service station was established at Port Eads, La., on July 1, 1888, to be supplied with a full set of self-registering meteorological instruments.

The observer at that place makes telegraphic reports to this office twice daily, during the hurricane season (August, September and October), and during the remainder of the year but one observation will be required. Reports from this station will be particularly valuable to the shipping community, since under existing circumstances the first intimation the service has of a storm in the Gulf is through the Signal Office at New Orleans.—*Monthly Meteorological Journal of the Louisiana Weather Service.*

The International Marine Conference.—An act of Congress, approved by the President July 9, 1888, provided for an International Marine Conference to secure greater safety for life and property at sea. Invitations have accordingly been extended to each maritime nation to send one or more delegates, to meet in Washington, April 17, 1889. The purposes of the conference are defined as follows: "To revise and amend the rules, regulations, and practice concerning vessels at sea, and navigation generally, and the 'International Code of Flag and Night Signals;' to adopt a uniform system of marine signals, or other means of plainly indicating the direction in which vessels are moving in fog, mist, falling snow and thick weather, and at night; to compare and discuss the various systems employed for the saving of life and property from shipwreck, for reporting,

marking, and removing dangerous wrecks and obstructions to navigation, for designating vessels, for conveying to mariners and persons interested in shipping warnings of approaching storms, of dangers to navigation, of changes in lights, buoys, and other day and night marks, and other important information; and to formulate and submit for ratification to the governments of all maritime nations proper international regulations for the prevention of collisions and other avoidable marine disasters."

"It will be understood by all States taking part in this conference that no questions relating to trade and commerce are within the scope of the discussion, and that in the disposition of any questions which may be presented to the conference, no State shall be entitled to more than one vote, whatever may be the number of delegates representing it."

The importance of this subject is so great, and the need for concerted international action so pressing, that a full attendance of delegates is confidently expected. This office will gladly do all in its power to facilitate the collection and proper presentation of data, and the officers in charge of the various Branch Hydrographic Offices will receive and forward any well-considered suggestions that may be handed to them. It should be remembered, however, that an intimate knowledge of all the conditions of the problem is very necessary to the suggestion or invention of any scheme likely to possess such merit as to render its adoption at all probable, and every plan should be thoroughly considered in all its details before being submitted. In this way the work of the conference itself will be greatly facilitated.— *September Pilot Chart.*

LOCAL STORMS IN OREGON.— Notwithstanding the fact that thunder-storms on the Pacific Coast are unusual, and severe ones a rarity, the month of May gave an unusual large number of them to Oregon, especially the southern part, and the month of June had one of the severest thunder-storms known in the history of Oregon. Lightning killed an Indian on the Siletz reservation (in Tillamook county). A cloud-burst occurred in

Morrow county, doing considerable damage, and hail in places cut down the grain, during the passage of the thunder-storm on the afternoon of Saturday, June 9th. Owing to incomplete reports the course of the storm cannot be accurately given. It was experienced in the eastern part of Douglas county, and from thence northward to the Columbia river, being in some places more severe than in others. The weather charts show that an area of low barometer came upon the coast from the sea on the 9th giving rain in the districts north of Cape Mendocino. This area of low barometer passed to the east, remaining nearly stationary for a time in Northern Idaho. The appearance of a well-defined area of low barometer, such as the one on the 9th, on the Northern Pacific Coast, in the summer is very unusual, whole seasons often passing without such an occurrence. The light summer rains of Oregon are usually due to the formation of a low barometer in the interior, which extends far enough west to give light showers, but not far enough to give well defined storm conditions. Hail and thunder-storms accompanied the passage of this "low," as they do the passage of barometric depression in the Eastern States in summer.—*State Weather Review.*

Our Prize Competition for Studies of Tornadoes.—As our readers are generally aware we attempt to promote the careful and general study of tornadoes by offering a series of prizes for the best essays on this subject. The rules governing the competion are:

1st. The essays must be in English or be accompanied by an English translation, and must be of a moderate length (from 2,000 to 5,000 words).

2nd. In order that the judges shall not know who are contestants, the essays must be signed by a *non de plume* and the real name and address of the contestant must be in a separate envelope addressed with the same *nom de plume.* These envelopes will be removed and retained by the editors before the essays are sent to the judges. The awards will be made by the judges without knowledge of the names of the contestants.

3rd. In order to exclude candidates without merit, and as a guarantee of good faith, a fee of five dollars will be required of all contestants. An equivalent for this will be given in subscriptions at the usual rates. For this purpose the money should be enclosed in the envelope with the real name and address of the writer.

4th. The papers must be in the hands of one of the editors by July 1st, 1889. At that time three independent and capable judges will be selected to whom the papers will be referred with instructions to judge them on the basis of originality and scientific value.

5th. The first prize of $200 will be given to the paper judged best; the second prize of $50 to that considered second best, and, farther the sum of $50 will be divided among those of the other papers judged worthy of commendation.

6th. The results of the competition will be announced in this JOURNAL. The papers of those competitors not receiving a prize will be held subject to their orders for a year, when, if not otherwise directed, they will be destroyed. The name of the competitor who receives the first prize will be published, but the names of those who receive the second and commendatory partial prizes can be withheld from the public if the authors so desire. In every case of awarded prizes the paper shall belong to this JOURNAL to publish as we see fit.

In laying before the public this proposal to promote the study of tornadoes, we have met with much kindness from the newspapers. The list of those which have aided us in the matter is a very long one, altogether too long to print here, however much we may wish to do so. We have generally been met with an intelligent appreciation of the great importance of our efforts, and to all these newspapers we wish to return our sincere thanks.

UNSEASONABLE WEATHER IN GREAT BRITAIN.—Quite unexampled cold weather was experienced in Great Britain, July 9 to 13. Concerning it the London *Times* says, on the 13th:

"Weather has continued in an unsettled and most unseason-

able condition in all parts of the kingdom. Thunder and lightning have been of frequent occurrence in most parts of England, as well as at some of the Irish stations, and the falls of rain at times have been very heavy. In the south of London on the 6th inst. an inch of rain fell in the short space of half an hour. Temperature has again been below the mean, the deficit in most districts varying from 4° to 6°. The highest of the maxima, which were recorded on somewhat irregular dates, ranged from 63° in 'Scotland, W.' to 71° in the 'Midland Counties' and 'England, S. W.' The lowest of the minima were generally registered towards the close of the week, when the thermometer fell to 32° in 'Scotland, N.,' 34° in 'Ireland, N.,' and to between 37° and 42° in most other districts. At Newton Reigny (in 'England, N.W.,') the minimum on the 9th is reported to have been as low as 30°. Rainfall has been rather less than the mean in Scotland as well as in the north-west of England and north of Ireland; but in most other parts of the kingdom an excess is shown, especially in the east and south of England. Bright sunshine has continued very deficient generally, the percentage of the possible amount of duration in most districts varying from 15° to 28°. In 'Scotland, N.' the percentage was 35°, and in the 'Channel Islands' 36°."

On the 11th there were falls of snow in Birmingham, North and East Derbyshire, Nottingham, the Lake District, Scotland, and on the east coast. The peak of Skiddaw was white, a circumstance which nobody living in the vicinity remembers to have occurred in July. A pilot who landed at Dover on the 11th in the afternoon, stated that severe weather had been experienced on the way down from the north of England, and that a snow-storm lasting nearly two hours was encountered just before entering the Channel. The continuous wintry weather had a very severe effect on fruit crops and young game, which were found dead in fields.

Fires and winter clothing were in demand in London on the 11th and 12th. Concerning London weather at that time Mr. G. J. Symons wrote to the *Times* on the 12th as follows:

"As a rule, the hottest day in the year in London is July 16.

We are therefore within a week of that date, and yet for two days I have been luxuriating in the warmth of an ever-ready gas fire.

"It would not be at all difficult to find two days in January warmer than these two in July; but, as it would be rather confusing to compare with two, I take only one—the first that comes to hand:

Date.	Minimum.	9 A. M.	Maximum.
	°	°	°
1887—January 1............	49.3	50.0	54.0
1888—July 11...............	42.8	45.4	55.7
1888—July 12...............	45.4	49.9	54.2

These two days have therefore been colder than that 1st of January—July 11 by 5.1°, and July 12 by 3.2°. Memory is not a safe guide, but I remember no parallel in July.

Some years back Mr. Glaisher, F. R. S., worked up the daily temperature at Greenwich from 1814 to 1873, and in that long period I can trace no days in July at all comparable with these, except two, one in 1836 and one in 1856. The precise figures are as follows:

Mean Temperature at Greenwich.		Mean Temperature at Camden-Square.	
	°		°
1836—July 20.................	47.7	1888—July 11...............	46.2
1856—July 8.................	48.0	1888—July 12...............	48.1

Wednesday, July 11, is therefore absolutely without precedent, and to-day is very nearly so."

RECENT CHANGES IN THE SIGNAL SERVICE OBSERVATIONS AND INDICATIONS.—On July 1, 1888, the tri-daily observations at the second order stations of the Signal Service which, since January 1, 1887, had been made at the hours of 7 A. M., 3 and 10 P. M., 75th meridian time, and telegraphed to Washington, were replaced by two daily telegraphic observations at 8 A. M. and 8 P. M., 75th meridian time. The 3 o'clock observation will be main-

tained through the year, but will not be telegraphed. The former method of making and recording the observations is continued, except that the maximum and minimum thermometers are read at 8 A. M. and 8 P. M., the extremes for the day being the readings at 8 P. M., when the instruments are reset. This last-named observation is made and recorded as was the former 10 P. M. observation, and the means are deduced from the two observations at hours of the same name. The 3 P. M. telegraphic observations is replaced by special telegrams in the case of cold waves, local storms or other marked phenomena. In order to follow the changes of atmospheric pressure and temperature a number of the important stations have been supplied with the French barographs and thermographs of Richard brothers. The former instrument has a set of aneroid boxes which, by a compound lever, inscribe the fluctuations of pressure on a revolving drum. The thermograph has a curved tube filled with alcohol and the alteration of form consequent on the temperature is recorded as in the barograph. When the record sheets are changed each week they are compared with the standard eye instruments, and the errors should not exceed 0.02 inch for the barograph or 1° F. for the thermograph. Thus the extremes of pressure and temperature and their times of occurrence are obtained, and from the hourly values, which are worked up monthly from the curves and transmitted to Washington, may be deduced the errors of the means of the present series of observations as compared with the means of the former series.

The object in changing the hours of observation was to give the indications officer at Washington more time to prepare the predictions and to furnish them earlier to the morning press, and to have the telegraphic reports charted at the local offices disseminated more rapidly and more generally than heretofore. The indications are now sent out from Washington about 10 P. M. and 10 A. M., for the morning and afternoon papers, respectively. The night indications commence at 8 P. M. the same day and the morning indications at 8 A. M., or immediately after their issue, instead of at 7 A. M. of the following day, and at 3 P. M. of the same day, respectively, as was formerly the case. During July

the indications covered a period of thirty-six hours from their issue, but, commencing with August, the time has been reduced to twenty-four hours. Two daily weather maps are now lithographed at Washington from the 8 A. M. and 8 P. M. observations, and are otherwise printed at certain secondary stations. The issue of maps from these stations dates from May, 1886, when Sergeant Cole, then in charge of the Boston station, commenced to chart the 7 A. M. reports from fifty stations which were tabulated in a bulletin for the press, and to manifold these charts by the cyclostyle process. A graphic representation of the weather conditions over the United States, as they existed four hours, previous, was thus presented to the public, while the corresponding Washington map, containing, however, more complete data, was not received at Boston until the next day. This system of preparing weather maps has since been adopted by the Service at many of its local stations. In July of this year, a process was introduced at Boston by which the wind and weather symbols for each station are set up in a slot corresponding to its position upon the base maps, while the tabular matter (maximum or minimum temperatures, wind velocity and rainfall) and the indications from Washington are put in type. After these data have been printed upon the maps the height of the barometer and thermometer at each station, the isobars and the isotherms are cyclostyled on them. Two editions daily of nearly 200 copies each are now issued within a few hours after the observations which they contain are taken, and are at once sent by mail to all the neighboring postoffices and to many institutions and individuals. With these data, in connection with the local observations, the public have the means to make their own local forecasts of the probable weather. This system of printing the maps is to be introduced at five of the most important stations throughout the country.

A. L. R.

THE CITY OF MEXICO.—Mr. Clarence Pullen describes in an interesting manner, in a recent number of the *Bulletin* of the American Geographical Society, a visit he recently made to this

city, and includes in his description some points of interest to our readers which, though not novel, are not yet generally understood. The city lies in a complete basin, with its own independent drainage. The Mexican Central Railway from the north passes through the rim of the basin in what Mr. Pullen calls "that wonderful opening completed after nearly two centuries of excessive labor and misadventure, known as the Tajode Nochistongo, an immense cañon-like canal, varying from 278 to 630 feet in width, from brink to brink, with a perpendicular depth of from 147 to 196 feet. It was cut in the 17th and 18th centuries, to drain the waters of the upper lakes of the valley, which, before its completion, often overflowed their beds and inundated the city. This wonderful ditch is 67,537 feet long, and, owing to the lapse of time since work on it was abandoned, has come to resemble a natural channel rather than a work of man."

The city itself is on the border of Lake Texcoco. "In the days when the city was the Aztec pueblo, Tenochtitlan, its site was upon a group of marshy islands in the lake, connected with the mainland by causeways, and easily defended by its fierce and independent people against assaults by their aboriginal enemies. The gradual subsidence of the lake through evaporation, the partial drainage of the valley by the Nochistongo, and the continual though slow accretion of the soil in a depressed location, have left the city of Mexico to-day on the mainland, a little above the surface of the lake; yet, anywhere within its limits at two or three feet below the surface, one at the present time finds stagnant water. There is no effective system of drainage, and the influence of such conditions on the health of people who live near the ground is naturally most disastrous. Despite the salubrity of the climate, fifty-five out of every thousand inhabitants die yearly in the city of Mexico. This mortality is confined largely to the poorer people, who live in huts on the ground, in squalid, over-crowded alleys, or as servants with quarters on the first floors of the houses of their employers. Those of the inhabitants who are well-to-do live in the upper stories of their houses, and so maintain a fair degree of health." To what Mr.

Pullen says may be added that what sewage there is, is emptied into Lake Texcoco, and that with rapid evaporation of the lake much of this refuse is exposed damp to the direct rays of a tropical sun, rendered all the more powerful by the high elevation of the city. Under such circumstances the stench of the decaying material reaches the city, and the effects on health must be most noxious. This state of affairs is well understood by Mexican scientists and statesmen, and the question of more effective drainage and sewage — a question the answer to which is here surrounded by difficulties of unusual magnitude —is being agitated. When a satisfactory and practicable solution of the problem has been found, it will doubtless be put into execution.

The old Spaniards were not only alive to the necessity of drainage,—witness the enormous undertaking of the Nochistongo canal,—they were quite as much alive to the necessity of an abundant supply of pure water. The hydraulic works of the 17th and 18th centuries, scattered over Mexico wherever needed, can hardly be surpassed elsewhere. "An interesting feature of the larger Mexican cities is the aqueducts that, through the hills and over arches of solid masonry, bring water to the people. Mexico is supplied by two aqueducts, one leading from Chapultepec, near at hand, the other fed by springs in the mountains of the Leones, about twenty miles southwest of the city, and which, from a point four miles away into the town, rests upon arches of brick and stone, 900 in number, which support the thick wall in which lies the open channel." Fresh water is, however, not generally distributed direct by pipe to the houses. It is brought to certain open fountains, and from thence distributed by hand. The water-carrier is one of the most marked features of Mexican streets, as he passes from house to house delivering water from a great earthen jar carried on his back and held by a strap passing across his forehead.

"Another noted feature of the valley is the Viga, or canal that conducts the waters of Lakes Xochimilco and Chalco into Texcoco. Along this canal one sees ever a procession of boats of various sizes, from the canoe in which the Indian woman

paddles to market, up to the great barges, with crowds of merry-makers bound on a day's excursion. There are various towns and picnic grounds along its edges, favorite places of resort of the poorer Mexicans on Sundays and feast days. At the town of Santa Anita, near the city of Mexico, are garden patches, separated by little strips of water, which were once the famous *chinampas*, or floating gardens of the Aztecs, but which in the subsidence of the waters of the lake have become part of the solid land."

As to the weather, Mr. Pullen says: "I arrived in the city on the morning of the 30th of September, just at the close of the rainy season, which begins about the 1st of July. During three months a heavy thunder-shower may be counted on for each afternoon. The rest of the year the weather is fair. . . . . I found at this season the most delightful weather, the air fresh and bracing, cool in the night and morning, but bright and warm in the middle of the day. One of the first cautions of my host was to take a light overcoat with me, whenever I went out of doors, and to walk always on the shady side of the street. The sunny side would not have been uncomfortably warm at this season, but so comparatively great are the damp and chillness of most of the house interiors that one is likely to take cold on coming in and sitting down after exercising in the warmth of the sun."

How Much Do We Really Know About the Weather?—"Whenever two Englishmen meet" said Dr. Johnson, "they begin to talk about the weather, each trying to inform the other of that which they know nothing about."

The force and application of the remark are unfortunately but too apparent, and I believe the general experience of all men will support the broad assertion that there is no topic about which the world talks more and knows less than the weather. Why is it so? What reasons are there for the existence of this desire to talk about the weather? One prime reason of course is found in the canon of society's law, that the weather is under all circumstances a proper preliminary, and a safe one,

to the more solid matters of conversation. It is agreed by all that statements about the weather are to be given and taken merely as so much small coin of the realm of agreeable intercourse, put in circulation for the sole purpose of stimulating the circulation of more weighty interchanges of thought and information. As small change it has this recognized and fixed place in the currency of talk, and no wise person attempts to urge it beyond proper limits. Woe very deservedly awaits the man or woman whose sole stock in conversation consists of platitudes about the weather.

A second reason may be in the fact that there undeniably is a charm and attractiveness about the subject, that few other conversational matters possess. After the affairs of 'self' and the concerns of those we are interested in, the weather lies uppermost I think in the minds of many men. With all unconscious sarcasm Mr. Scott begins his "Hand-Book of Meteorology" with the expression, "Almost every one imagines himself a *born* meteorologist!" Is it not so? The desire, the inclination (perhaps an inherited one) to venture abroad their own opinions and speculations in the form of weather prognostics, is certainly very prevalent.

If we may judge from the old saw, "what men do not know, they are most prone to speculate about," the people of to-day do not know over much about meteorology, and the remark of the great lexicographer about his countrymen (and himself included) applies equally well to our day and country. It is but natural that our thoughts should turn to and concern themselves with the medium in which we move and live; and from the earliest of times, man has been compelled to form for his own satisfaction and for the peace of mind of his fellows, hypotheses and explanations of the phenomena of the atmosphere. Once interested and the attention aroused the mind is drawn on to interpret according to its own light the various phenomena that crowd forward for recognition and explanation. It is at this point the untrained mind loses the true balance and falls in error. It is so hard to resist the temptation to tell the world information which you are certain you have acquired, of a mat-

ter which you are equally certain the world knows nothing about.

And again there is just enough of the element of uncertainty about the weather to make it particularly fascinating, to challenge speculation, and to dare those who may claim to know, to an issue. Interest is always manifested in that which is not indeed doubtful but uncertain, and in the wildest predictions that have ever been made has rested the possibility of their fulfillment and some slight element of truth. That is why we have seen the public mind thrown into a state of nervous excitement by the published prophecy of some irresponsible individual, that great storms would happen on certain dates! And this also explains the publication of fore-casts and predictions in almanacs, weather guides and farmers' annuals.

The element of uncertainty is the really disturbing factor, and the public forgets and loses sight of the great truth, that if the person making the prediction only knew more, he would know enough not to venture on predictions.

With the advancing knowledge of the laws of storms and the steady increasing prominence of the science of meteorology, this out-put of miscellaneous misinformation must diminish.

In meteorology, appearances are as deceptive as elsewhere! The weather is not always just what it appears to be! Paradoxical as it may seem, we have no right to say, "It is going to rain!" because it looks like rain. A brief experience in predicting will teach one to appreciate the remark of the old settler in a certain western town, to the tenderfoot who said, "It is going to rain!" "Perhaps it will, stranger, but I've been here ten years and it has never rained yet!"

We have only to look back at the opinions held in past times to realize where appearances backed by unbalanced speculation may lead. Think of St. Augustine arguing that there were windows in the firmament, through which when opened, the rains poured. In the 17th and 18th centuries, throughout the greater part of Europe, ecclesiastics preached and taught that the air was full of devils, and that all storms, tempests and especially thunderstorms were the direct work of these, evidenc-

ing their spite against man, and were only to be successfully fought off and guarded against by agencies purely spiritual. And so were published* "Hand-books of Prayers against Bad Weather with Sighs for Use when it Lightens fearfully," and "Cries of Anguish when the Hail Storm is drawing on!"

We laugh at these, and yet one meets daily with experiences which are as ludicrous and give occasion for the thoughtful to enquire "How much do intelligent people really know about the weather?" I give just a few of these experiences.

On being told that it was necessary to apply a correction for temperature to the barometer, the visitor said:

"What! Is the barometer affected by temperature?"

"Yes!"

"Well, I should think then that out-of-doors would be the proper place for it!"

Then there is a very common impression, aside from all joking, that meteorologists are in some way concerned directly in the manufacture of the weather, and that a great deal of work has to be done when the weather is stormy, and very little or none, when the weather is clear. But the most trying experience of all is to be compelled to listen to some narrative in detail, of the experience of the narrator in some blizzard, or tornado, or hurricane. Unintentionally, in all such cases people exaggerate both their own adventures and the description of the storm, and the commonest terms are so misapplied that one begins to think the popular knowledge of meteorology is hardly beyond that of the little girl of four years, who astonished the Indications Officer at St. Paul one very cold morning, by insisting that she "knew the thermometer was 400 degrees *before* zero!" A. M.

THE RAINFALL AT FORT LEAVENWORTH, KAN.—In 1837 rainfall observations were instituted at Fort Leavenworth under the supervision of the post surgeon, and the record was continued, with but few breaks, until October, 1883. In the latter year, in

*See "Meteorology," by President A. D. White, Reprint from *Pop. Sci. Monthly*, July, 1887.

view of the proximity of the Signal Service station in Leavenworth City, the authorities at the War Department, or the officers at the fort, suffered this magnificent record to be discontinued. The length of the series, surpassing any other record west of the Mississippi, and antedating by almost twenty years the settlement of Kansas by the white man, has made it of especial value as evidence upon the question of a secular change in rainfall over the Western plains.

The observations up to 1874 were rendered generally available by their publication in the 'Smithsonian Precipitation Tables' and in the 'Report of the Kansas Board of Agriculture for 1874;' for the years 1871 to 1880 they were published in 'Professional Paper No. IX.' of the Signal Service; and for 1881 to 1883 they have not been printed, or at least have not become generally accessible. The series subsequent to 1873 seems, moreover, to have been little used, and discussions of secular change in rainfall have generally been made by completing the Fort Leavenworth series since 1873 with the Signal Service records at Leavenworth City, the entire comparability of the two series being assumed without investigation or proof.

That this assumption is quite unscientific, and that it is liable to lead to erroneous results, does not need to be argued before the careful meteorologist. The difference in the rules and methods of observation and the spirit of the observers, as well as the difference in the locations and exposures of the gauges and in the gauges themselves, furnish abundant room for systematic discrepancy.

With the record thus constructed out of the two series of observations, an average increase of seven inches seemed to have occurred during the past twenty years, and this result has been widely used to confirm the belief in a permanent increase in the rainfall over the Western plains. For the reasons above stated, this conclusion seems to me to stand in need of a complete re-examination. In a preliminary survey of the Fort Leavenworth observations as printed, errors were discovered that showed the necessity of a thorough scrutiny of the original data (see *Science*, XI. No. 272).

In order to make the desired examination, I have visited Fort Leavenworth, and through the courtesy of Major Alfred A. Woodhull, Surgeon U. S. A., was enabled to make copies of the original records for the years not hitherto published, and for the periods needing confirmation. I am also indebted to Major Woodhull for certified copies of a portion of the records that have heretofore been incorrectly printed.

In view of the error already discovered,— namely, that the measured snowfall in January, 1871, had not been reduced to inches of water,— I examined all of the data since 1870, to correct, so far as possible, all other errors of the same kind. The record of snow for the winters of 1870–71 and 1871–72 were found to be given in this way, and comparison with the Signal Service observations also indicated that the reduction had been neglected in a few instances in subsequent years. This critical examination of the original observations has led to the construction of the accompanying table of monthly totals:

Monthly Precipitation at Fort Leavenworth, Kansas.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1870.......	—	—	—	—	—	—	—	—	—	—	—	1.27*	41.70
1871.......	1.12	3.37	1.70*	1.22	2.00	5.44	1.63	4.66	1.85	4.00	3.94†	0.46	31.39
1872.......	0.20	0.87†	2.30	4.50	8.15	3.64	9.99†	6.83	4.05	0.83	0.00	2.85	44.21
1873.......	0.98	1.35	1.80	4.30	5.03	3.11	3.12	1.40	2.53	0.91	0.87	5.24†	30.64
1874.......	1.44	1.07	1.50	1.40	1.00	3.55	2.95	1.69	4.76	0.37	3.46†	1.02	24.21
1875.......	0.05	1.25†	1.70	2.23	4.17	2.34	6.72	3.15	0.78	0.74	0.40	1.98	25.51
1876.......	1.20	0.44	5.71	6.19	6.17	4.81	2.28	4.21	3.62	3.00	1.91	0.66	40.20
1877.......	1.65	0.58	4.14	5.16	7.61	7.59	4.36	2.15	1.88	4.36	1.71	2.82	44.01
1878.......	1.36	2.88	1.95	2.76	3.96	4.36	1.89	2.38	2.61	0.54	2.28	2.40	29.37
1879.......	0.12	0.35	0.06	3.44	2.05	7.89	3.59	0.62	2.79	3.85	6.26	1.85	32.87
1880.......	2.14	1.55	2.53	1.46	3.90	0.96	5.86	6.68	1.68	2.40	1.80	0.40†	31.36
1881.......	0.15	4.61	2.20	1.67	3.14	3.73	2.00	1.92	5.23	4.46	1.40	0.96	31.47
1882.......	1.07	0.88	0.76	3.84	2.61	2.82	3.00	0.65	1.18	2.28	1.92	1.06	22.07
1883.......	0.48	2.05	0.72	1.27	6.65	12.16	2.25	1.97	0.85	8.31†	2.02†	0.65†	39.38

* Observations by Mr. F. Hawn. † Observations by Signal Service.

Important changes in the values for April, May, July, and August, 1871, are corrections of serious errors existing in the published observations, the corrected values having been furnished by Major Woodhull. For those months in which the record at the fort is missing, namely, February and July, 1872, and October to December, 1883, the Signal Service observations have been inserted to complete the series.

The Signal Service record has also been substituted in November, 1871, and December, 1880,—months in which the fort record is manifestly recorded improperly, but for which the correct record cannot safely be inferred; and also in December, 1873, November, 1874, and February, 1875, for portions of which the fort record of snow is apparently measured carelessly, or recorded without reduction, but of whose error the evidence now at hand is not entirely conclusive.

Although in these several instances the fort record has been completed by the use of Signal Service observations, the series still remains essentially homogeneous and comparable from 1837 to 1883.

Combining the whole series in ten-year means, we have the material for ascertaining the existence of any secular change:

Period.	No. of Years.	Amount.
1837–46	10	30.4
1847–56	10	32.3
1857–65	9	33.7
1867–76	10	33.2
1877–83	7	32.9

The increase of seven inches shown by the combined Fort Leavenworth and Signal Service records has largely disappeared. Examining, now, the average annual rainfall from 1872 to 1883 given by the Signal Service record and the record at the fort, we find that the former is 38.5 inches, and the latter 33.0 inches, showing a discrepancy between the two of five and a half inches.

To what this discrepancy is due,— whether to differences in the rules of observation or to an error of ten per cent. in the Signal Service gauge (as was the case at Providence, R. I.), or to some other cause,— I do not know; but it is fairly manifest that the conclusions based on the assumed comparability of the two series are quite worthless.— [*Science*].

GEO. E. CURTIS.

BIRMINGHAM, CONN., June 30.

DEW.— In this journal, Vol. III, p. 7, there is a short comment upon the results obtained by Mr. John Aitken, in Scotland, upon the formation of dew. The full text of the original paper has just reached this country in Trans. Roy. Soc. Ed., Vol. XXXIII, p. 9. As this question is of importance it may be well to give the summary here with a few comments. Mr. Aitken writes:

"1st. Vapor is almost constantly rising from grass land, by night as well as day, in our climate.

"2nd. Under most conditions this is also true of uncultivated areas of soil. It follows that dew never 'falls' on the earth, and is only deposited on plants, and other bodies not in good heat communication with the ground.

"3rd. The greater part of the dew on bodies near the ground is formed of the vapor rising at the time from the earth, and very little from the vapor that rose during the day.

"4th. Dew forms copiously on roads, but owing to the stones being good conductors of heat, the vapor is deposited on the under sides of the stones and not on top.

"5th. Wind hinders the formation of dew by preventing an accumulation of damp air near the ground.

"6th. The 'dew-drop' formed on grass and other plants is not dew at all, but is formed of the exuded sap of the plant.

"7th. Almost all substances, such as black and white cloths, garden mould and grass, radiate equally well at night. Among the few exceptions observed are polished metals and sulphur.

"8th. A covering of snow on the ground lowers the mean temperature of the air."

Mr. Aitken's experiments have been exhaustive, and occupy 56 quarto pages. The results with some exceptions might have been anticipated from what was known before. The experiment with flat trays, deposited on grass or soil, which condensed moisture on the inside and none on the top, is very unsatisfactory, and certainly does not show that dew comes from the soil. Very often nearly as much dew forms on a tin roof fifty feet from the soil, as on the latter, and in this case absolutely none can come from the roof. When a tray is placed over sod the included air acts as almost a perfect barrier to the radiation from the sod, in consequence the top of the tray is kept above the dew-point, and of course there is no dew, while the vapor from the warm soil is condensed on the inside of the tray, which is cooler than the soil from a partial radiation on top. It certainly is true that the under side of leaves do not have more dew than the upper, and it will probably be found that the deposition of dew is directly dependent on the amount of cooling of the surface. The most important point is admitted, and that is that dew is condensed moisture from the air.

We must take serious exception to section (4). The reason why dew is not deposited in abundance on roads is because the air is drier there, and also because the soil never gets cooled down sufficiently. Wind serves to prevent radiation, and hence prevents cooling to the dew point. Mr. Aitkin has given us a very interesting item regarding the "dew-drop," and this will bear more research. It may be noted that the plants on which this appearance was found to the highest degree were those of the greatest vitality and presumably were cooled down more by radiation on this account. Again these plants (leaves) were not moistened by rain, but it was collected in little drops at the tips of the leaves. Both of these considerations would serve to explain the phenomenon without recourse to exudation. Experiments showing what such leaves will do when under pressure or under any but natural conditions, are not at all satisfactory.

To the method of experiment under section (7) we must take most serious exception. Results obtained by Mr. Glaisher and a host of others, cannot be thus easily brushed aside. Mr.

Aitken's radiation thermometers do not in any way measure the radiative power of substances. We note but one singular contradiction. It was found repeatedly that the soil on the road was at least 4° *warmer* than the sod close by, and yet by cutting the grass and placing it on one radiation thermometer, and sprinkling a little of the soil on another and allowing both to radiate, it was found that the soil thermometer was *cooler* than the grass.

The idea is slowly gaining ground that in meteorology we must study nature just exactly as we find her, and must not carry our laboratory methods and experiments or mathematical theories, etc., one whit farther than a practical questioning of nature will allow us. Yet after a hundred years experience in meteorology, we still find most extraordinary attempts to torture nature and make her yield up her secrets by most unnatural methods and speculations regarding her modes of action.

* Since writing the above I have had an excellent opportunity for testing some of the points at issue. These observations were made in a small park in a large city where there could hardly be as much dew as in the country. The whole park which was slightly rounded at the centre, presented a most enchanting sight; myriads of points and droplets were throwing back reflections of the sun, just appearing in the east. I found the most dew on the hairy plants, generally each individual hair had a tiny sphere at the tip. In the case of *sorrel, plantain* and *dandelion* with smooth leaves, the surface was uniformly wet and the drops were replaced by little splashes where the dew was sufficiently abundant. In a bed of variegated plants, about 18 inches high, in which the ground was completely hidden from view, only the top leaves had any dew, the rest of the leaves being perfectly dry, as well as the ground, the dew point not having been reached.

Smooth boards had far more dew than rough ones, though this may have been due in part to the fibres of the boards being different. Pieces of white paper scattered about had the dew collected in well defined circular disks and not over the whole

* **Note.—Added August 27.**

surface. But the most interesting phenomena were the beautiful spheres of dew collected mostly at the tips of the grasses though often in the centre of a leaf if it was horizontal for any distance. These were from one to three millimeters in diameter and were often found upon nearly erect grasses 100 mm. (4 in.) above the general grass surface. These were much larger at the tips of the more hairy grasses, and also when the tip was bent over so that the action of gravity could assist in forming the drop. These drops have given Mr. Aitken the idea of exudation from the plant, an idea, however, which is most clearly untenable from the following considerations:

1st. The drops were found at the tips of dead leaves, though not quite as large owing to less cooling of the leaf.

2nd. The same drops were to be seen on paper.

3rd. The same drops were found in abundance on cobwebs.

4th. On many grasses the only drops to be seen were at the exact tip, though the edge of the grass had the same surroundings.

In all these cases I took particular notice that the drops could not have come from other plants near by. In all instances and over the whole ground it was plain that the surface which had cooled most during the night had the most dew.

A careful search was made for an explanation of the anomaly of the existence of a drop in apparent defiance of the law of gravity. The grasses examined had two characteristics in this connection, some were very hirsute, having hairs one to two millimeters in length, but at the same time having shorter and much thicker set hairs underneath; others had no pubescence distinctly visible to the unaided eye, but this was felt very plainly on passing the blade between the thumb and finger. The first described blades had from three to four times the dew that the second had, and it was distributed all along the blade, though the largest drop was at the tip. The second class presented a very peculiar appearance, there seemed to be no moisture along the blade, but just at the tip came the beautiful drop. In all cases the pubescence was pointed toward the tip of the blade. If the blade was drawn through the fingers from the

base toward the tip nothing was felt, but a contrary motion at once arrested the movement and revealed the sharp points. This then gives an explanation of the march of the drop upward and against gravity. In cobwebs and in the pubescence (more or less hairy) of the grass, we have an almost perfect radiation to the sky, in consequence the dew will collect on the cobweb, and at the tip of each projecting point; in the latter case in little globules. The collection of the dew in a drop on a cobweb has generally been ascribed to the movement of the spider, but it is probable that a microscopic examination (which has not yet been made) will show very slight adherence between the dew and the web, and that this formation is largely due to gravity. Still another explanation seems satisfactory. Whenever a carefully prepared surface of Regnault's hygrometer is slowly cooled to the dew-point the deposit of dew does not appear to form a continuous layer, but is rather projected upon the silver in little droplets. This effect is most beautifully illustrated when the dew-point is several degrees below freezing, in this case each separate frost particle is distinctly visible. Now if the same effect is produced on the cobweb, then the little spherules of dew would finally become so large that they would touch and running together form the large drop. As to the drops on the grass, it is suggested that a tiny droplet would naturally be formed at the tip of each hair where it was coolest; it could not go down the blade because the hair is pointed upward. Suppose, however, that two droplets upon adjacent hairs, one above the other, become large enough to touch each other; they would immediately coalesce as do drops of pure mercury. The combined droplet, however, could not go to the lower hair, because both are pointed upward, hence the droplet leaves the lower hair, and is pulled up to the upper. This action would tend to begin at the top of the blade first, and hence as the cooling proceeds the droplets would gradually travel upward from point to point, and finally thousands of them would collect together at the tip of the blade and form the large drop. It is admitted that this explanation is hedged about with some difficulty, but it seems plausible.

Z.